

## **Refrigeration Monitor**

### **5 Field of Invention**

This invention relates generally to the monitoring and diagnosis of faults occurring in commercial refrigeration equipment.

### **10 Background of Invention**

Refrigeration equipment is used widely to preserve the quality and to extend the shelf-life of many commercially valuable products - principally food but also such items such as blood, plasma and other tissue. It is rare today to find a produce store of any size that does not have some refrigeration equipment. Generally, the sale of meat and dairy products without adequate refrigeration is prohibited by regulation. Refrigeration equipment may be located close to the origin of the foodstuff (be it a dairy, a slaughterhouse, packing or manufacturing plant) for temporary storage, during its transportation (on trucks, trains or ships), in warehouses or depots where it is again temporarily stored, and in retail outlets and restaurants where it is sold.

The most widely-used refrigeration systems rely on the cooling provided by an evaporator located within the space to be cooled or in thermal communication with the space to be cooled. This cooling is obtained by the rapid expansion of gas. A refrigerant gas is contained in a sealed conduit forming a closed loop. A compressor compresses the refrigerant in its gaseous phase into a condenser. The compression causes a heating of the refrigerant, and that heat is drawn away by a stream of air or water flowing over a heat exchanger associated with the condenser. Usually this loss of heat causes the refrigerant to liquefy. Liquid refrigerant is released through an expansion valve downstream of the condenser into an evaporator, in which the pressure is appreciably lower than that of the region upstream of the expansion valve. In the evaporator, vaporization of the liquid and expansion of the gas so produced occur. This expansion and vaporization require energy, which is taken as heat from the walls and surroundings of the evaporator, causing a cooling in the vicinity of the evaporator (including cooling of any chamber or the like with which the evaporator is in thermal communication). To facilitate heat exchange, the evaporator is typically provided with a heat exchanger and cooling fins, and a fan or the like is typically used to maintain a stream of air over the evaporator. The evaporator accepts heat from the air stream, reducing its temperature. The cool air so produced is circulated by the fan within the chamber to be cooled.

Many of the earliest refrigerators used ammonia as the refrigerant. This choice was thermally effective, but highly toxic. More recently some members of the class of chlorinated fluorocarbons ("CFCs"), such as dichlorofluoromethane  $\text{CCl}_2\text{F}_2$ , have been used as they are odourless and non-toxic in moderate quantities. However, CFCs have been found to be deleterious to the environment, with particularly troubling effects on the ozone layer of the atmosphere. More recently CFCs have been replaced with hydrocarbons such as cyclopentane.

The evaporator may cool sufficiently to form ice on its surface and, over time, ice build-up can become a problem. The ice acts as an insulator, with the consequence that the evaporator's heat exchanger may become blocked so that air cannot flow effectively over its surface. Periodically it is necessary to defrost the evaporator to remove the coating of ice. This is usually done using a defroster in the vicinity of the evaporator that employs a heater, hot gas or hot water to remove the ice build-up.

Typically, refrigeration systems are controlled either by one or more thermostats located in the space to be cooled or by a sensor measuring the refrigerant pressure in the evaporator. When one or more of these sensors indicates that the temperature or evaporator pressure has risen sufficiently to exceed an appropriate selected upper threshold, the compressor is activated, and cooling begins. Cooling continues until either a selected lower temperature limit is reached or the pressure in the evaporator has fallen sufficiently, at which time the compressor is turned off. Ideally, the compressor's ON and OFF cycles are regular and predictable (except of course when the refrigerator is opened to permit insertion or removal of its contents).

The impaired performance of a refrigeration unit is costly. Food that is not kept within an optimal temperature range loses its quality and can spoil; if it can still be sold, it typically commands a lower price. Taking a refrigeration unit off-line to be repaired means that there is less space available for the storage or display of produce. With a smaller variety of produce on display, sales are likely to be reduced. Typically, the value of the produce in even a modest cooler of a small grocery store is measured in the thousands of dollars; the value of cooled produce in a larger supermarket can be in the hundreds of thousands of dollars.

Refrigeration systems use energy to provide cooling. If they are working inefficiently, there is an additional cost for the energy consumed.

Problems with refrigeration equipment that lead to faults or failure include the following:

- Leaks of the refrigerant. The piping and seals that contain the refrigerant are subject to vibration stresses that eventually can cause cracking or rupture of the metal. Corrosion from oxidation or the effects of acid impurities can also cause leaks.

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- Heat exchangers used in the condenser and in the evaporator are designed to present a large surface area and to be made of thin metal for better heat conduction. This makes them fragile and prone to breaks if they are mishandled.

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- A compressor typically has a pump driven by an electric motor. Both the pump and the motor have mechanical parts including valves, bearings, seals and brushes, all of which wear with use over time, leading to possible breakdown.

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- Fans are frequently used to maintain streams of air over the condenser (to remove heat) or over the evaporator (to distribute cold air). The fans have mechanical and electrical parts that can wear and ultimately fail.

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- The heat exchangers can become coated with dust, dirt or ice or their heat-exchange surfaces blocked with items such as plastic bags or paper.

- The power supply may be subject to voltage spikes, may suffer periods of low voltage, be interrupted or overloaded.

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- The defroster may lose power or, if the defroster is of the hot-gas type, the solenoid may seize, and the defroster will be unable to remove ice build-up from the evaporator.

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The early detection of fault conditions can mean the avoidance of more costly repairs. Quite commonly, electro-mechanical devices such as pumps and fans show signs of poor performance well in advance of failure. Being able to spot and correct a deteriorating situation before it becomes critical can save considerable down time and expense.

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For example, a slow leak of refrigerant will probably produce a predictable pattern of system operation. At first, with less refrigerant to work with, the compressor will have to run for a longer on-cycle to achieve an equivalent cooling effect. If the compressor is regulated by a thermostat within the refrigerated compartment, the length of the on-cycles will continue to increase until a point is reached where the compressor does not shut off at all. Alternatively, if the compressor

is regulated by the pressure at its intake, the drop in pressure from the loss of refrigerant will cause the compressor to be shut off early, typically just after it has started up. This is often referred to as "short-cycling". In some cases, the protective circuitry of the compressor will ensure that the compressor is shut down, sometimes without any warning. This may protect the compressor from damage but may jeopardize the food stored in the refrigerated compartment. Another problem may be that the compressor refuses to start. Diagnosing why this is so is greatly simplified if the service technician has access to the recent history of the compressor's operation. Further, if the length of the on-cycle can be routinely monitored, the problem may be detected before it has become critical.

As a further example, an electro-mechanical device like a compressor has bearings, bushings and its drive motor has brushes. These are all parts subject to wear. Over a period of time there will be increased resistance caused by friction, particularly if lubrication has been inadequate for any appreciable time. This resistance can be readily observed as a persistently increasing current drawn by the compressor during operation and by a longer period of high current draw during start-up. Knowing well in advance that the compressor is beginning to have trouble is of great value as it enables operators of the equipment to plan for a compressor replacement at a convenient time and avoid a complete breakdown.

There is a considerable variation in the operating environment of refrigeration equipment; it is difficult to predict what are normal ranges for various operating parameters of the equipment. Variations in performance are to be expected - for example, ambient temperature, number of people in the vicinity, the mass of stored material in the refrigerator or freezer, etc. will vary appreciably from day to day and sometimes from hour to hour. There may be variations in the power supply voltage. The quality of wiring and connections will vary from installation to installation. And there is typically significant variation in the number of times in a day the cooling/storage compartment is opened, and for how long. The situation is further complicated as some enterprises will have a number of coolers, chillers and freezers operating.

The diagnosis of problem situations is normally a matter that needs attention from a qualified technician and is not usually addressed by staff untrained in refrigeration. To avoid the risk of lengthy down time, such technical help may be required 24 hours per day and is sometimes not to be found close at hand. This can cause the following types of difficulties:

- The technician may be called in when he is not needed. For example, a warning that the compressor has been running for longer than usual may simply be due to the fact that the freezer door has been left open.

- The technician may not be advised correctly or be advised too late of the problem situation. In either situation, the technician may not be able to respond in time to prevent a critical situation.

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- The technician may not have available sufficient information to make an accurate diagnosis of the problem. If he is lucky, upon arrival, the technician may find that the refrigeration unit still functions and that some sensor information is available. But the system may by the time the technician arrives have reached a critical situation and may have had to be shut down, either manually or by protective

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circuitry. When this is the case, the technician may have limited information available from which to diagnose the problem. In some circumstances, attempts at diagnosis can lead to further damage. With inadequate information, repairs are often more costly as components that are working properly are sometimes needlessly replaced in an attempt to fix the problem.

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Many types of refrigeration monitoring equipment have been devised previously. However, such equipment has typically dealt with some but not all important aspects of the problems facing service technicians. In particular:

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- (1) Designs of prior monitoring equipment typically do not permit a comparison of pre-failure equipment performance with the problem performance leading up to the failure. Prior designs typically do not allow for the recording of operational parameters as historical time series for monitoring purposes. A "time series", as used herein, means a series of values of a parameter obtained and recorded at successive times, usually with equal intervals
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- between the times.

US patent 5,209,076 (Kauffman *et al.*, 1993) teaches the measurement of a selection of operational parameters and comments on the value of their collection over an extended period of time. US patent 4,090,371 (Keane, 1978) teaches apparatus for monitoring the

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characteristics of lubricating oil at significant points within the compressor and points out that recording the precursor history prior to malfunction can provide diagnostic information for speedy repair. However, in neither of these patents is there any teaching in any enabling disclosure of the details of how the collection and recording of useful historic data might be accomplished.

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- (2) Prior teachings typically fail to take into account the idiosyncratic nature of the components installed in any particular refrigeration unit. For example, consider the problem faced by

an engineer or technician to determine a reasonable value for the average duration of the compressor on-cycle. There are many manufacturers of compressors, each of whom typically sells many models of compressor. Further, the performance of any particular compressor, even of the same make and model, varies. Once a compressor has been selected, the duration of the on-cycle will depend on many other factors - such as the other components installed, the size of the refrigeration compartment, the amount of insulation installed, ambient temperature, and how much unrefrigerated material is within the refrigeration unit. Typically, this has meant that reference values for operational parameters have been selected with a good measure of guesswork, or by way of averaging over a large number of units, and that historical parameter values recorded as a time series have not been used.

(3) The prior art typically does not disclose adequate means for providing supporting data to a service technician to improve his ability to diagnose a problem. In some cases, refrigeration monitoring equipment does nothing more than shut down equipment that may be suffering from some problem within a selected set of problems. In a few cases, the service technician can find out which operational parameter has a value indicating a fault. Prior monitoring apparatus typically does not include means for notifying the technician of possible alternative causes for the reported problem.

(4) Frequently, refrigeration monitoring equipment includes checks on the values of operational parameters such as refrigerant pressure, the temperature in the refrigerated compartment and the currents drawn by and voltages applied to electrical equipment. However, few designs of prior monitoring equipment take into account all of the principal problem types with which a technician must cope. For example, prior monitoring devices typically do not include means for comparing the duration of the compressor's on- and off-cycles against normal values.

In the prior art, a number of issued patents address the problem of detecting leaking refrigerant. A common solution to this problem is to detect the presence of the refrigerant, or a tracer chemical mixed with the refrigerant, as it leaks into the air surrounding the refrigeration unit. An example of this approach is set out in United States patent 6,131,636 (Singh *et al.*, 2000) in which the inventors teach the use of dye that fluoresces under ultraviolet light.

Alternatively, low refrigerant charge can be detected by observing the pressure either at the suction side of the compressor (as in US patent 5,481,884 Scoccia, 1996) or at the

discharge side of the compressor (as in US patent 5,586,445 Bessler). However, the pressure of the refrigerant needs to be measured after the system has had a chance to stabilize, and this is difficult to determine without an effective record of the operating parameters each as a time series. For example, US patent 5,044,168 (Wycoff 1991),  
5 discloses a method for detecting low refrigerant levels by comparing the suction pressure and the discharge pressure while the compressor is idle during a defrost cycle.

US patent 5,934,087 (Watanabe et al., 1999) teaches the use of two temperature sensors and a means for measuring the cumulative running time of the compressor to judge a  
10 refrigerant leak. This approach suffers from the drawback that the monitor will report a refrigeration leak only once the loss of refrigerant is almost complete and the compressor is running for an extended on-cycle. This approach may provide a correct diagnosis of the problem; however, diagnosis may come too late, in that by the time such a report is received, the temperature in the refrigerated compartment may have risen and jeopardized  
15 the quality of its contents. Although Watanabe recognizes the importance of the duration of the on-cycle, the apparatus disclosed does not record the compressor's current drawn as a time series, and comparisons of on-cycles over a period of time are not possible. Further there is no indication how reference values are to be determined.

US patent 6,354,093 B2 (Davis et al., 2002) teaches the measurement of the most recent compressor running time, the evaporator coil temperature, last door-alarm time, last defrost  
20 time period, door-closed time period, and discharge-line temperature, to determine when a defrost operation is required and to monitor for condenser clogging and refrigerant leaks. The efficacy of the algorithms presented in Davis rely on having threshold values available  
25 for all of the operational parameters, but Davis provides no enabling disclosure on how these values are to be chosen. Further, the algorithms presented do not take into account all the fault events that could occur. For example, the claimed control system fails to detect the following fault situation:

- the defrost operation is not overdue (that is LDTP < TLDTP);
- 30 • the compressor running time (CRT) exceeds the desired threshold value (TRT);
- the discharge line temperature (DLT) is within reasonable bounds;
- the reason for the long CRT value is due, not to the loss of refrigerant or the clogging of the condenser, but rather to the malfunctioning of the compressor.

US patent 4,553,400 and 4,612,775 (Branz, 1985 and 1986) disclose a selection of  
35 sensors combined with a digital display to monitor a section of operating parameters, including a direct measurement of the refrigerant level.

A number of patents deal with the detection of problems with the compressor. In US patent 4,090,371 (Keane, 1978) the inventor teaches apparatus for monitoring the nature of the lubricating oil at significant points within the compressor. Keane makes the point that recording the performance history prior to malfunction can provide diagnostic information for speedy repair, but provides no disclosure of how this might be done.

Other prior patents focus on different items of equipment or specific narrow methodology for dealing with a small number of faults but not all of the more common ones. For example, US patent 5,009,075 (Okoren, 1991) describes a fault determination method for refrigeration units that incorporate an electronic expansion valve and electronic controller. In US patent 6,205,798 B1 (Porter *et al.*, 2001) the inventor teaches a method for the automated detection of leaks through the compressor. US patent 4,848,096 (Funahashi *et al.*, 1989) discloses means to make an automatic diagnosis of the pressure sensors as measured on the input and output sides of the compressor without disassembly of the compressor.

In US patent 6,332,327 B1 (Street *et al.*, 2001), the inventors disclose apparatus and methods particularly suited to control refrigeration equipment in large supermarkets. Typically such equipment makes use of multiple compressors, each of which has a number of sensors. The inventors disclose a safety and control module incorporating a bus for communication between modules to simplify the wiring for communication between the system's active components. This makes it possible to distribute the intelligence required to operate multiplexed compressors.

(5) The prior art includes reference to the use of telecommunication equipment to notify a service technician of a problem. For example, Kauffmann (*supra*) teaches the desirability of automatic notification of a service technician over a telephone line. However, Kauffmann fails to provide any disclosure detailing how this might be carried out.

US patent 5,136,281 (Bonaquist, 1992) discloses a "Monitor for remote alarm transmission".

US patent 4,482,785 (Finnegan *et al.*) discloses means to alert technicians by telephone of any unusual temperature detected within a freezer compartment.



- (6) The prior art typically discloses no means for a service technician to connect a monitor electronically to refrigeration equipment from a remote location and to access historical and real-time data representing the values of significant operational parameters.

## 5 Summary of the Invention

In this specification, it will usually be presupposed that the equipment to be monitored is refrigeration equipment whose cooling compartment or chamber stays above freezing temperature. However, in many respects, the operation in principle of a freezer is identical or analogous to that of a refrigerator. And the operation of heat pumps and air conditioners is also essentially analogous to the operation of refrigerators. With appropriate selections and modifications, it will be apparent to those skilled in such technology how to adapt to the monitoring of such analogous equipment the teachings of this specification relating to refrigeration equipment.

- (1) In one aspect of the invention, a novel process is disclosed to obtain the values of selected parameters from associated sensors located on one or more refrigeration units, convert those values to digital form in standard units, and at regular intervals to record the digital data in a database. Apparatus is disclosed that implements the method.

In this aspect of the invention, the database contains a historical record of the values of selected important refrigeration parameters during the recent operation of the refrigeration unit. This record is of particular value to service technicians, as it makes possible the detection of faults that previously went undetected. For example, the duration of the on-cycle of the compressor is a critical measure of the refrigeration unit's performance. In many situations the detection of the deterioration of the refrigeration unit's performance can be inferred from the detection of a steadily increasing compressor on-cycle. Such fault detection provides an early warning in advance of catastrophic failure. Note that the off-cycle duration can also be important; compressor valve problems are sometimes revealed by analysis of both the on-cycle and off-cycle.

- (2) In a further aspect of the invention, a specific combination of computer hardware and software elements is disclosed that provides an embodiment of the functionality of the process described in aspect (1) above. The preferred combination is premised upon the use of suitable sensors (that are frequently analog sensors) for monitoring selected parameters of given refrigeration equipment. Such combination preferably comprises data collection, processing and operations equipment, and associated peripherals such as

display monitors and analog-to-digital converters. One or more signal reception units each comprising a microcontroller with associated memory and communication components operates under the control of a computer program. The sensors may each be connected to an associated signal reception unit. Alternatively, a single signal reception unit could receive input from all of the sensors and provide data output in a form that preserves the association of value data with the sensor source of such data. A computer suitably programmed, which may incorporate the microcontrollers or the microcontroller functionality just mentioned, causes the reading of the values of signals generated by the sensors, conversion of the values of any analog signals to digital values, and supply of the resulting digital values to an alarm, monitoring and reporting unit (MRU) via a communications interface. The MRU may comprise a general-purpose microprocessor having associated memory, permanent storage and communication components, operating under the control of a computer program. In addition to or as part of the MRU, a receiver may be provided for receiving selected data and performing one or more operations thereon. The receiver may provide a suitably interfaced display of data, may provide an alarm, may provide printed data reports, and/or may provide an interactive interface to enable a monitoring technician (say) to interrogate the MRU. The receiver preferably has means for providing an alarm (in the event of an existing or incipient fault condition) , a display for selected sensed parameter values (current or historic or reference or combinations thereof) and/or existing or incipient fault conditions, and reports on selected sensed parameter values (again including current or historic or reference or combinations thereof) and/or existing or incipient fault conditions.

The computer program operates on a stream of digital sensor data received from each or the signal reception unit via one or more communications ports. The data received include time-related values obtained periodically from each sensor. The computer program causes such data to be stored in a historical time-series database preferably located in permanent storage. Such data are useful to technicians and equipment manufacturers as they provide a historical record of the performance of the equipment.

In the preferred embodiment, the program executes a set of performance checks on the digital sensor data to detect faults. If a fault is detected, the program causes a suitable message to be prepared comprising at least the location of the equipment, the nature of the fault and the date and time the fault was detected. The message is sent by conventional telecommunication means to a receiving station, which may, for example, be the pager of a service technician.

(3) In a further aspect of the invention, a novel process and suitable novel apparatus for practising the process are provided for detecting faults in a refrigeration system. It has apparently gone unrecognized by anyone developing prior monitoring apparatus and methodology for use with refrigeration equipment that if one wishes to be comprehensive about fault diagnosis, one must make a carefully considered selection of the system parameters. According to the invention, a preferred selection of refrigeration system parameters is made, sensors are provided to sense the values of these selected parameters, and their values are repeatedly collected at predetermined time intervals from the sensors, which are located on or in association with components of the refrigeration equipment or apparatus peripheral thereto such as the power supply. In a subsequent step, the values of the parameters detected in each parameter value sensing cycle and relevant values stored for earlier cycles are used as inputs to a novel set of performance checks

The preferred selected refrigeration system parameters for an electrically powered refrigerator with a defroster are:

- (a) the alternating current line voltage  $V$  (assuming an AC rather than a DC electric power supply);
- (b) the compressor current  $A$ ;
- (c) the defroster current  $D$ ;
- (d) the refrigeration chamber temperature  $T$ ;
- (e) the evaporator pressure  $LP$ ; and
- (f) the condenser pressure  $HP$ .

If there is no defroster, the defroster current would of course not be monitored. If the defroster is present in the equipment but not a self-contained electrically powered device - perhaps instead a hot gas defroster, usually some other parameter can be substituted for the defroster current. For example, if a solenoid opens and closes a conduit valve for the hot gas, the solenoid current could be monitored.

In some cases, one would measure DC current instead of AC, depending upon the electric power source used to power the equipment or selected components of the system.

If the equipment is not electrically powered, again it will often be possible to monitor some substitute set of parameters for the electric current and voltage parameters mentioned above. For example, if the compressor is driven hydraulically, or is gas or diesel powered, usually some

substitute measurement can be made, such as fuel consumption, hydraulic fluid flow, hydraulic pressure at specified locations - e.g. upstream and downstream of the compressor, or the like.

Finally, although the parameters listed above are considered to be suitable for small-to-medium size electrically powered equipment monitoring, substitute parameters might be measured for larger installations. For example, if a compressor is very large and draws a heavy electric current under load, an ammeter suitable to measure such large current may be expensive. In such case, it may be preferable to measure a substitute set of parameters, perhaps doing so even if the result is some loss of precision - an approximation of the value sought. One might, for example, measure line current rather than compressor current draw, and measure the voltage drop across the compressor. Or one might use a wattmeter to measure the power drawn across the compressor in a succession of time intervals. Other parameter substitutions suitable for use in particular installations will readily occur to those skilled in this technology.

What is paramount in the parameter selection aspect of the invention is the selection of a set of parameters that together will generate useful reference, historic and present data so that a technician, preferably assisted by suitable data analysis software, may diagnose and remedy the majority of common problems encountered in typical refrigeration installations.

The performance checks to be performed on the preferred embodiment of the refrigeration equipment, making use of the selected parameter measurements, at each iteration of such measurements, are presented in detail below. In summary, with reference to the preferred embodiment of the invention in which electrically powered equipment is being monitored, there are 18 preferred warnings/alerts from performance checks, as follows:

- (a) Power-outage alert
- (b) Power-restored warning
- (c) High-voltage warning
- (d) Low-voltage warning
- (e) Locked-rotor amperage alert
- (f) Long compressor on-cycle warning
- (g) Long compressor on-cycle alert
- (h) Short compressor on-cycle warning
- (i) Short compressor on-cycle alert
- (j) Long compressor off-cycle warning
- (k) Long compressor off-cycle alert
- (l) No-refrigerant-pressure alert (no refrigerant pressure on intake side of compressor)

- (m) Cut-out-pressure-too-low warning (pressure on intake side of compressor too low while the compressor continues to pump)
- (n) Cut-in-pressure-too-high warning (pressure on intake side of compressor too high while the compressor has not yet begun to pump)
- (o) High-pressure warning (compressor is pumping and the pressure on the condenser side of the compressor is too high)
- (p) High-pressure alert
- (q) High-defroster-current warning
- (r) Low-defroster-current warning

The purpose and effect of the performance checks is to identify situations in which the values of the sensed parameters indicate that the performance of the refrigeration system has changed significantly and probably requires the attention of a service technician. The performance checks are selected to detect situations of two types. Certain performance checks identify less serious situations which are reported as "warnings" and typically identify either an incipient fault or an existing fault that will not jeopardize the immediate ability of the monitored equipment to refrigerate, albeit perhaps inefficiently. Other situations are considered to be critical or more serious and are reported as "alerts".

(4) In a further aspect of the invention, a specific combination of computer hardware and software is disclosed that provides an embodiment of the functionality of the process described in (3) above. The computer hardware is as described in (2) above. The computer program installed to operate the hardware, however, in the preferred embodiment executes instructions to conduct the performance checks summarized above and that are described further in the detailed description of the preferred embodiment below.

(5) In a further aspect of the invention, a novel process ("learning mode") is provided for the calculation of preferred reference values of configuration parameters to be stored for subsequent use with performance checks of the type referred to in (3) and (4) above. Such reference values of the selected configuration parameters represent set values or limits on ranges of values at or within which the operation of a refrigeration unit, as measured by sensed continuing values of refrigeration system parameters, is considered to be satisfactory.

In a first step, reference values of the selected configuration parameters are determined or calculated from historical records retained in permanent storage or from reference values believed to be reliable, such as manufacturers' recommended values for equipment

components. Optionally and preferably, these reference values may be updated and revised by a skilled technician familiar with the equipment and with other sources of information such as safety regulations and understanding of the preferred operation of similar configurations of components. The measured, calculated or determined configuration parameter values, revised by a technician as required or preferred, are then stored in permanent memory storage.

The technique for determining the reference values of configuration parameters is general and can be applied to a variety of parameters, stored in a number of different ways for use with many different sets of performance checks. However, in the preferred embodiment described herein, the historical records are created and stored in a database by the process described in (1) above and/or by the apparatus described in (2) above, and the reference values of configuration parameters so determined are subsequently used with performance checks of the type referred to in (3) and (4) above.

The advantages of the learning-mode technique are:

(a) The reference values measured, calculated or determined represent the actual operation of a configuration of a number of components. Although fairly good estimates or ranges for the configuration parameters can be supplied by manufacturers or technicians, these do not take into account the particular nature of the installation, the patterns of usage, ambient climate conditions or seasonal climate fluctuations. So typically the manufacturers' recommended reference values for a given component of the refrigeration equipment may not precisely coincide with preferred configuration values for an actual configuration of installed equipment including such component.

(b) Learning-mode measurements may be repeated should the components of the refrigeration unit, the sensors, or the performance-checking software change.

(6) In a further aspect of the invention, a specific combination of computer hardware and software is disclosed that provides an embodiment of the functionality of the process described in (5) above. The computer hardware is a general purpose personal computer readily available commercially, having a microprocessor, memory, permanent storage and telecommunications components. The computer operates under the control of a computer program which executes instructions to effect the process disclosed in (5) above.

- (7) In a further aspect of the invention, a process is disclosed whereby values of refrigeration parameters, stored as time series data in a historical database, are retrieved for subsequent review for the diagnosis of refrigeration equipment faults.

5 The preferred process as performed by the preferred apparatus is as follows:

- 10 (a) The interrogating computer requests from the signal reception unit or set of signal reception units data representing the values of sensed operating parameters from a historical time series database that may be located in the vicinity of monitored refrigeration equipment or may be remotely located (data storage may be arranged in network memory, in an internet database, or as may be found suitable by the user).
- 15 (b) The computer arranges the transfer of the requested data to selected permanent storage, and if so required, makes use of conventional telecommunications equipment and protocols to transfer data;
- 20 (c) For the convenience of an attending technician, the computer arranges the repeated display of successive sets of the values of each of the sensed refrigeration parameters (or, if desired, selected ones of them) on a display screen, each set of values corresponding to one point in time, and the interval between successive displays of data values preferably being controllably adjustable to speed up or speed down the display of the data.
- 25 (d) The computer software operates to execute performance checks at each iteration of the parameter values. Analysis of the results of the performance checks leads to the detection of existing or incipient fault conditions in the refrigeration equipment. In at least some cases, the performance checks will involve a comparison of present or immediately preceding historic data with reference values
- 30 obtained in learning mode.
- 35 (e) If a fault condition is detected, the computer software operates to cause a report, alert or warning to be transmitted to a recipient such as an observing service technician. The transmission identifies the whereabouts and nature of any fault conditions detected.

The foregoing process has several advantages, most notably that a service technician can observe the recent operation of the refrigeration equipment without having to visit the site. Further, the technician is able to review the recent history of the equipment's performance, possibly speeded up, to assist in diagnosing problems.

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Of value is the ability of the apparatus performing the foregoing process to display the refrigeration chamber temperature at suitable selected times, and to provide and/or preserve the data in a form suitable for presentation to a health inspector

- 10 (8) In a further aspect of the invention, a specific combination of computer hardware and software is provided that provides an embodiment of the functionality of the process described in (7) above. The computer hardware is a general-purpose computer, preferably for the sake of economy a personal computer readily available commercially, having a microprocessor, memory, permanent storage and telecommunications components. The
- 15 computer operates under the control of a computer program that executes instructions to effect the process disclosed in (7) above.

The diagnosis of an existing or incipient fault condition is preferably performed automatically or semi-automatically with some interaction between the monitoring apparatus and the user of that

20 apparatus.. To that end, suitable algorithms may be devised that, when implemented by the monitoring computer, analyze alert or warning conditions and/or related parameter or reference data relating to such conditions, and provide at least a first-attempt diagnosis of the equipment problem that apparently has prompted such alert or warning. However, there is extensive variation from one refrigeration equipment installation to another, and the monitored parameters may not

25 be identical for each item of monitored equipment. Furthermore, reference data for any two installations may vary considerably. So to a large extent, the choice of algorithms to be used is within the designer's preference. The present invention is not directed to any such choice as such, nor even broadly to automatic diagnosis. Rather, the present invention provides apparatus and a methodology that is capable of providing a foundation for such diagnostic analysis as the

30 designer may wish to employ for any particular refrigeration equipment installation.

Other features and advantages of the invention will become apparent from the detailed description and the claims that follow. Note that the system designer may select for inclusion in the retrievable data for examination by a technician or data processing by the system, whatever

35 information or parameter values the designer considers suitable. For example, records of all those contractors who have been responsible for the installation of the monitors and sensors for a selected unit of refrigeration equipment could be stored. Or records of service previously



performed on a selected unit of refrigeration equipment could be stored. The invented system is not constrained by the particular selection of data or of monitored parameters included by way of exemplification in the detailed description that follows.

## 5      **Brief description of the drawings**

Figure 1 is a schematic diagram of a refrigeration unit with sensors installed to measure selected operational parameters, in accordance with an embodiment of the invention.

10      Figure 2 is a schematic drawing of the principal hardware components of a preferred embodiment of a refrigeration monitor and associated signalling devices according to the invention, detailing the reception of signals from the sensors, the conversion of the signals to digital form, their recording and analysis, and the distribution of warnings and related information by various communication means to technicians or observers.

15      Figure 3 is a schematic flowchart representing the operation of the software in the alarm, monitoring and reporting unit.

20      Figure 4 is a reproduction of a PC computer monitor display representing the screen layout used to set a selection of configuration parameters relevant to the particular refrigeration unit, for use by the software in the alarm, monitoring and reporting unit and the PC Monitor.

25      Figure 5 is a reproduction of a PC computer monitor display representing the screen layout used to set a selection of configuration parameters relevant to the installation as a whole, for use by the software in the alarm, monitoring and reporting unit and the PC Monitor.

Figure 6 is a schematic flowchart representing the operation of the real-time monitoring function of the PC Monitor software.

30      Figure 7 is a reproduction of a PC computer monitor display representing the output of the PC Monitor software operating in real-time monitoring mode.

35      Figure 8 is a reproduction of a PC computer monitor display representing the output of the PC Monitor software in chart display mode, the monitor displaying a chart of sensor values for a representative detected alert.

Figure 9 is a portion of the chart display of Figure 8, magnified in the vicinity of the alert.

Figure 10 is a reproduction of a PC computer display representing the output of the PC Monitor software in service-history display mode, the PC Monitor displaying a representative entry in the service history for a selected refrigeration unit.

- 5      Figure 11 is a schematic drawing showing an alternative embodiment of the invention in which more than one refrigeration unit is monitored.

Figures 12 to 19 inclusive are screen prints or partial screen prints from a monitor used to monitor an exemplary refrigeration system, using the methodology and apparatus of the present invention.

10

Figure 12 depicts an initially viewed dialog box presenting options for adding or removing and/or configuring refrigeration equipment or for retrieving or uploading data.

15

Figure 13 depicts a dialog box premised on the selection by the user of the second of the five options displayed in the dialog box of Figure 12, presenting a further three options to the user.

Figure 14 illustrates a monitor screen print of a dialog box presenting a representative five choices of refrigeration equipment to be selected by the user.

20

Figures 15 and 16 illustrate dialog boxes permitting the user to select default or reference settings for the monitored equipment. The Figure 15 options are directed to parameter value settings whereas Figure 16 permits selection of default options for the various types of equipment and equipment components displayed.

25

Figure 17 illustrates a dialog box for displaying selected present or historic parameter data.

Figure 18 is a screen print displaying selected parameter graphs associated with a selected message field in the Alerts window of the dialog box of Figure 17.

30

Figure 19 is a screen print displaying historic data graphs for selected parameters.

### **Detailed description**

35

The preferred embodiment of the invention is described with reference to Figures 1 to 10.

Figure 1 shows a schematic drawing of the principal components of a representative refrigeration unit, shown generally as **100**, for cooling a refrigerated compartment **102**. The refrigeration unit

**100** is constructed conventionally of conventional components. The temperature **T** in the refrigerated compartment **102** is measured by a thermometer **136** whose output is provided at terminal **140**.

5 A suitable refrigerant is contained within piping **104** forming a closed loop. A compressor **106** is powered by electric current obtained from an AC line **126**. The voltage **V** and current **A** supplied to the compressor **106** are measured by a voltmeter **128** and an ammeter **124** respectively. The voltmeter **128** provides a signal representative of voltage **V** at terminal **148** and the ammeter **124** provides a signal representative of current **A** at terminal **146**.

10 When in operation, the compressor **106** pumps the refrigerant through the piping **104** in the direction of the arrows **120**. In certain situations, such as when the refrigerant must be pumped against gravity for a considerable height, an auxiliary pump or pumps (which are not shown) may be employed to assist in moving the refrigerant.

15 The refrigerant is pumped from the compressor **106** via the pipe **104** to and through an expansion valve **110**. The expansion valve **110** restricts the flow of refrigerant and creates a back pressure so that the refrigerant is compressed, particularly in the vicinity of the condenser **108**. The compression of the refrigerant causes an increase in its temperature. The temperature is reduced by forcing air from a fan **114** over a heat exchanger (not shown in Figure 1) in close thermal contact with the condenser **108**. The pressure **HP** of the refrigerant within the condenser part of the loop is measured by a sensor **134** that provides an output pressure data signal at terminal **142**.

20 The refrigerant is forced by the compressor **106** through the expansion valve **110** into an evaporator **112**. The pressure **LP** of the refrigerant within the evaporator part of the loop is measured by a sensor **132** whose output signal is available at terminal **144**. The pressure difference between pressures **LP** and **HP** is maintained by the combined action of the compressor **106** and the expansion valve **110**. The expansion of the refrigerant downstream of the expansion valve **110** causes it to cool. In a common configuration, the cool refrigerant within the evaporator **112** draws heat from air circulated by a fan **116** over a heat exchanger (not shown in Figure 1) that is in close thermal contact with the evaporator **112**. The resulting cooled air flows to the interior of the refrigerated compartment **102**, absorbing heat from its walls and contents. The air completes a closed circuit through a duct returning to the vicinity of the evaporator **112** (the two air conduits illustrated on either side of the fan **116** may be thought of as representing exit and inlet conduits from the evaporator compartment to and from the refrigerated compartment **102**).  
35 Alternatively, the evaporator **102** itself can be placed within the refrigerated compartment **102**.

Whenever there is a difference in pressure across the expansion valve **110**, refrigerant flows through the expansion valve **110** to the evaporator, causing (as already mentioned) a cooling effect in the evaporator **112**. Periodically, as determined by control circuitry, the compressor **106** runs to maintain or increase the pressure difference between pressure in the vicinity of the condenser (HP) and the pressure in the vicinity of the evaporator (LP). Such control circuitry is entirely conventional and typically uses the temperature within the refrigerated compartment **102** and the pressure in the evaporator **112** to determine when the compressor **106** should be powered on. The associated control circuitry and compressor switch are not illustrated in Figure 1.

At selected times or under selected conditions, the compressor **106** is halted so that evaporator **112** may be defrosted. For this purpose, commonly, a defroster coil **118** is energized to heat the evaporator **112** and remove any build-up of ice. The defroster **118** is powered by electricity from an AC line **126**; the current D drawn for this purpose is measured by an ammeter **130** whose output is provided at terminal **138**. In an alternative configuration (not shown) solenoid valves are used to direct the hot compressed gas from the compressor directly to the evaporator, by-passing the condenser **108** and the expansion valve **112**. This hot gas defroster is particularly effective as the hot gas passes directly through the heat exchanger of the evaporator **112**, and removal of ice can be relatively rapid.

Conveniently, all output terminals **138** through **148** are located in proximity to one another for connection to suitable selected monitoring, control or recording devices (not shown in Figure 1).

For many monitoring, recording and control purposes, the sensed values are most conveniently provided as digital values. If the sensors **124**, **128**, **130**, **132**, **134** and **136** do not directly provide a digital output, analog/digital converters (not shown in Figure 1) may be interposed between the sensors **124** to **136** and the terminals **138** to **148**, or may be interposed between the terminals **138** to **148** and the associated monitoring, recording and control devices (as is shown in Figure 2).

The sensors used may be conventional and are readily available commercially. Examples of suitable sensors are as follows:

Manufacturer	Part Number	Sensor Range	Parameter sensed
Texas Instruments	2CP5B0520150ANY	0-150 psi	Low pressure, LP

Texas Instruments	2CP5B0520150SNY	0-500 psi	High pressure, HP
AAC	108-270C	0-270 volts	Line voltage, V
AAC	1005-200	0-200A	Compressor current, A
AAC	1005-200	0-200A	Defrost current, D
Dallas Semiconductor	DS18S20	-10°C to 85°C	Temperature, T

Of the sensors selected in the table above, the two pressure sensors **134** and **132**, the voltage sensor **126** and the two ammeters **124** and **130** are analog devices producing output signals in the range 0 - 5 volts. The Dallas Semiconductor thermometer **136** is a digital device producing a signal with 9-bit resolution.

Figure 2 shows a schematic drawing of the preferred embodiment of monitoring apparatus and associated devices arranged in accordance with the invention. Hardware for such apparatus is assembled as two parts: a signal reception unit ("SCU") **202** and an alarm, monitoring and reporting unit ("MRU") **204**. Conveniently, at least the signal collection unit **202** is attached to or proximate to each refrigeration unit **100** (Figure 1); the MRU **204**, if desired, may be located in a clean area reasonably close to the refrigeration unit **100** or may be remotely located, or more than one such MRU may be provided. In this particular embodiment, a single signal reception unit **202** serves to collect data from all of the sensors **138** to **148**.

Those signals from the sensors **138** to **148** that are not already in digital form (typically sensors **138** and **142** to **148** if the equipment selection conforms to the exemplary selection in the above table) are first converted to digital form by the analog-to-digital converter **206**. A microcontroller **208** repeatedly reads the sensor signals, reformats them and makes them available as digital sensor data at the interface **210**. The microcontroller **208** may be a standard commercially available processor such as a MicroChip PIC16C770 processor. The following description of the format of the digital sensor data and the protocol for its transfer from the SCU **202** to the MRU **204** is exemplary; the system designer may vary the details to meet the prevailing requirements for any given installation.

In the following description, hexadecimal values are shown prefixed by "0x". For example, the hexadecimal value for the integer 32 would be shown as 0x20.

In this example, the format for the digital sensor data, originating at the SCU **202** for transmission to the MRU **204**, has 16 bits for each data value. There are 12 bits for the data value itself and 4 bits to record the reference number of the sensor from which the signal originated. Each digital sensor data value is laid preferably as follows:

Digital Sensor Data Value: Byte 1

B <sub>4</sub>	B <sub>5</sub>	B <sub>6</sub>	B <sub>7</sub>	B <sub>8</sub>	B <sub>9</sub>	B <sub>10</sub>	B <sub>11</sub>
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Digital Sensor Data Value: Byte 2

C <sub>0</sub>	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	B <sub>0</sub>	B <sub>1</sub>	B <sub>2</sub>	B <sub>3</sub>
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The digital value of the data from a given sensor is stored as an integer with 12 bits of precision, in bits, B<sub>0</sub> to B<sub>11</sub>. Each sensor is assigned a unique channel number that is stored in bits C<sub>0</sub> to C<sub>3</sub>, thereby permitting the output signals from the various sensors to be distinguished from one another. There is also one reserved channel. Suitable channel numbers are:

Channel	Signal
0000	Low pressure LP <b>144</b>
0001	High pressure HP <b>142</b>
0010	AC line voltage V <b>148</b>
0011	Compressor current A <b>146</b>
0100	Defrost current D <b>138</b>
0101	Reserved
0110	Temperature T <b>140</b>

The microcontroller **208** is initially in an idle state. The microcontroller **208** is readied for operation upon receipt of a two-byte initiating sequence. The first byte of that sequence specifies which of seven sensor values are to be sent. The second byte contains a coded value for the sample rate.

Each of the seven low-order bits in the sensor selection byte indicates whether a particular sensor signal should be transmitted. The high-order bit is always set to 1 so that the sensor selection byte will not be confused with the sample rate byte.

Sensor Selection Byte

Bit	7	6	5	4	3	2	1	0
Value	1	x	x	x	x	x	x	x

The sample rate byte is, in this example, one of the following values :

Sample Rate Byte

Byte	Sample rate
0x80	1 Hz
0x81	2 Hz
0x82	5 Hz
0x83	10 Hz

A third byte is then used to start (0xF1) or stop (0xF0) transmission. Upon receipt of the start byte, the microcontroller **208** repeatedly transmits to the serial port **210** the 16-bit formatted digital sensor data value for each of the sensors selected in the sensor selection byte, and repeats this transmission at the frequency specified by the sample rate byte. Any other byte received by the microcontroller **208**, such as 0x0F, cause the microcontroller to halt processing and reset to its initial idle state.

The MRU **204** combines a general purpose microprocessor and RAM memory **218** with a serial (or USB, as appropriate) interface **216** to the SCU **202**. Data can be sent and received over this port asynchronously to and from a reciprocal port **210** on the SCU **202**. The microprocessor **218** is further connected to local permanent storage facility **222** in which received data can be stored in selected files. A variety of suitable permanent storage options are commercially available, all of which combine small size and low power consumption with high reliability and high capacity. Particularly suitable are "disk on a chip" products, such as the DiskOnChip Millennium Plus product available from M-Systems of Newark, California. The microprocessor **218** can also communicate through additional interfaces for external communications. Typically provided are a serial port **220** and an Ethernet™ port **224**.

With reference to Figure 3, on power-up, the operating system and MRU monitoring software are automatically loaded (step **302**) from files **316** resident on a permanent storage medium or facility.

The MRU monitoring software performs the following functions:

- (1) The contents of one or more configuration files are read and their contents used to set configuration parameters **304** used by the MRU software. Typically, the configuration parameters pertain to either the site or the particular unit of refrigeration equipment. The tables below, collectively referred to as the CONFIG data, contain a selection of parameters suitable for the preferred embodiment as described herein, but it should be understood that the contents of these files may vary to suit the precise details of the implementation selected by the system designer.

(a) Parameters unique to a particular location

GP	The grace period before a second paging call is made.
F <sub>1</sub>	Frequency at which sensor values are captured from the SCU.
F <sub>2</sub>	Frequency at which sensor values are checked and logged in the History database.
LOC	Site location.
UNIT	Description of refrigeration equipment.
PH	Pager phone number.
RETRY	Number of retries to reach a technician by pager.
WAIT	Delay before sending retry messages to a technician.
COMMS	Baud rate, parity. stop bits, data bits. flow control.
DIAL	Modem control codes to dial out.

(b) Parameters unique to a particular unit of refrigeration equipment.

TYPE	Unit type - cooler or freezer.
COND	Condenser type - air-cooled or water-cooled.
CONTROL	Regulation - pressure alone, temperature alone or both.
DEFROST	Defrost type - pump down electric, electric, hot gas or air.
SS	Sensor signals to monitor.
PA	Parameters to convert of ammeter sensor values to amperes.
PV	Parameters to convert of voltmeter sensor values to volts.
PHP	Parameters to convert condenser pressure sensor values to psi.
PLP	Parameters to convert evaporator pressure sensor values to psi.
V <sub>max</sub> , V <sub>min</sub>	The maximum and minimum line voltages typically expected.
A <sub>max</sub>	A maximum value of the current drawn by the compressor as it starts up.
A <sub>1</sub>	Duration of normal maximum current draw A <sub>max</sub> during start-up.
LP <sub>min</sub> , LP <sub>max</sub>	The lowest (and highest) pressures to be reasonably expected in the evaporator before the compressor shuts off (or starts up).
HP <sub>1</sub> , HP <sub>2</sub>	Reasonable and maximum upper values for the pressure in the condenser during compressor operation.
D <sub>min</sub> , D <sub>max</sub>	The lowest and highest defroster currents to be expected.



ON <sub>avg</sub>	The average on-cycle duration.
ON <sub>1</sub> , ON <sub>2</sub>	Factors used to calculate a reasonable upper limit and maximum acceptable duration of the compressor's on-cycle.
ON <sub>3</sub> , ON <sub>4</sub>	Factors used to calculate a reasonable lower limit and minimum acceptable duration of the compressor's on-cycle.
OFF <sub>avg</sub>	The average compressor off-cycle duration.
OFF <sub>1</sub> , OFF <sub>2</sub>	Factors used to calculate a reasonable upper limit and maximum acceptable duration of the compressor's off-cycle.

5

10

(2) The serial port **216** (Figure 2) is opened for asynchronous communication (step **306** in Figure 3) with the SCU **202**. The communication parameters contained in the COMM parameter are used to initialize the serial port **216**.

15

(3) Configuration data is sent (step **308**) to the microcontroller **208** (Figure 2) via the serial port **216**. The configuration data typically includes bytes to reset the microcontroller (0x0F), set the sensor signal selection (0xDF), set the sample rate (0x83) and start transmission (0xF1).

20

(4) At suitable intervals, as determined by the F<sub>1</sub> frequency parameter from the CONFIG data, the 16-bit digital sensor values provided by the SCU **202** for each selected sensor are read (step **310**) from the serial port **216** and converted to more usual units (that is, pressures in pounds per square inch in U.S. practice, currents in amperes and voltages in volts). The conversions make use of the PA, PV, PHP and PLP constants contained in the CONFIG data.

25

These step **310** values, together with a unique key comprising a record sequence number and a timestamp, are stored (step **318**) in a History database **320** stored in the permanent storage facility **222**. For ease of reference, values stored in the History database corresponding to a particular time period are shown with a "t" subscript (that is V<sub>t</sub>, A<sub>t</sub>, D<sub>t</sub>, T<sub>t</sub>, LP<sub>t</sub> and Hp<sub>t</sub>).

30

Additionally, during step **310**, values of the temperature T at 8 hour intervals for typically the past 30 days are stored in a file in the permanent storage facility **222**.

35

Optionally, the digital sensor values obtained at step **310** may also be displayed on a terminal monitor (not shown as such) attached to the MRU.

- (5) Each set of digital sensor values is checked (step 314) by the MRU software for warnings or, more seriously, alerts. A number of the checks described below involve a comparison of present values with threshold or normal or reference values of various selected parameters. These threshold or normal or reference values are all provided from the CONFIG data, described above, where they have either been set by a technician, the system designer based on manufacturer's recommendations or have been measured by means of the learning mode of the system (described in (8)(c) below), and preferably have been adjusted and updated based upon an analysis of the monitored equipment and its installation, knowledge of analogous systems, and experience. The preferred performance checks for AC-powered refrigeration equipment are the following:

(a) Check voltage

Event	Test
Power outage alert	$V_t = 0$ and $V_{t-1} \neq 0$ The voltage has fallen from a non-zero value to zero.
Power restored warning	$V_t \neq 0$ and $V_{t-1} = 0$ The voltage in the previous period was zero and the voltage in the current period has now risen above zero.
High voltage warning	$V_t > V_{\max}$ and $V_{t-1} > V_{\max}$ The voltage has risen too high in two consecutive periods.
Low voltage warning	$V_t < V_{\min}$ and $V_{t-1} < V_{\min}$ The voltage has fallen too low in two consecutive periods.

(b) Check compressor operation

Event	Test
Locked rotor amperage alert	$A_t = A_{\max}$ for $A_1$ seconds. The compressor has drawn an abnormally high current in consecutive periods. This is usually indicative of a locking of the compressor rotor.

(c) Check compressor on-cycle

Event	Test
Long compressor on-cycle warning	$A_t = 0$ and the compressor current $A_t$ has been non-zero for more than $ON_1 \times ON_{\text{avg}}$ periods.
Long compressor on-cycle alert	$A_t = 0$ and the compressor current $A_t$ has been non-zero for more than $ON_2 \times ON_{\text{avg}}$ periods. ( $ON_2 > ON_1$ .)

Short compressor on-cycle warning	$A_t = 0$ and the compressor current $A_t$ has been non-zero for fewer than $ON_3 \times ON_{avg}$ periods.
Short compressor on-cycle alert	$A_t = 0$ and the compressor current $A_t$ has been non-zero for fewer than $ON_4 \times ON_{avg}$ periods. ( $ON_4 < ON_3$ .)

5

(d) Check compressor off-cycle

Event	Test
Long compressor off-cycle warning	The compressor current $A_t$ has been zero for more than $OFF_1 \times OFF_{avg}$ periods.
Long compressor off-cycle warning	The compressor current $A_t$ has been zero for more than $OFF_2 \times OFF_{avg}$ periods. $OFF_2 > OFF_1$

10

(e) Check compressor low pressure

Event	Test
No refrigerant pressure alert	$LP_t = 0$ There is no refrigerant pressure on the intake side of the compressor.
Cut out pressure too low warning	$LP_t < LP_{min}$ and $A_t \neq 0$ The pressure on the intake side of the compressor has fallen too low and the compressor is still pumping.
Cut in pressure too high warning	$LP_t > LP_{max}$ and $A_t = 0$ The pressure on the intake side of the compressor has risen too high and the compressor has not yet started.

15

20

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(f) Check compressor high pressure

Event	Test
High pressure warning	$HP_t > HP_1$ and $A_t \neq 0$ The compressor is pumping and the pressure on the condenser side of the compressor has risen too high.
High pressure alert	$HP_t > HP_2$ and $A_t \neq 0$ The compressor is pumping and the pressure on the condenser side of the compressor has risen dangerously high.

30

(g) Check defroster operation

Event	Test
High defroster current warning	$D_t > D_{max}$ The defroster is drawing an unexpectedly high current.
Low defroster current warning	$D_t < D_{min}$ The defroster is drawing an unexpectedly low current.

Note that the performance checks can be made in a number of different ways. For example, the check for the locked rotor amperage reads:

$$A_t = A_{max} \text{ for } A_1 \text{ seconds}$$

The particular way in which this is carried out may vary at the discretion of the designer. The preferred technique as is described in this specification is based on the assumption that the values needed to carry out the test are available in a historical time series database. On this premise, one of a number of ways in which the performance check could be done is by following this measurement/logic sequence:

- Is the value in the current period equal to  $A_{max}$  ?
- If so, examine the values of the amperage values stored during the past  $A_1$  seconds. If they are all equal to  $A_{max}$ , then the check is satisfied and a locked rotor amperage alert should be signalled.

However, it will readily occur to those skilled in the technology that one might use a different procedure for establishing the  $A_{max}$  value and comparing it to the current value  $A_t$ . By way of example, after establishing the  $A_{max}$  value, an alternative for the locked rotor amperage check would be as follows:

- Keep a count of the number of consecutive periods in which the measured current equals  $A_{max}$ . This could be done by storing a record that had two fields: timestamp S and count of consecutive periods N. This would be interpreted to mean that the current delivered to the compressor had held at the maximum value for N consecutive periods commencing at time S.
- The test according to this alternative procedure would then be: Has N (in seconds) exceeded  $A_1$  ? If so, then a compressor high-amperage alert would be sent to the receiver (e.g., a technician's monitor or pager).

Note that while as an example the above discussion has made use of the particular performance check on the basis of which the locked compressor rotor amperage alert might be transmitted, similar variants or substitutes could be readily devised for the other performance checks. Further alternative performance check methodology will readily occur to those skilled in the technology.

(6) If any of the checks detect a fault (either a warning or an alert), a message is sent to the pager **326** of a service technician. With reference to Figure 2, the alert or warning message is sent via the serial port **220** and modem **226** over a telephone line **228** to the pager **232** (incorporating its own modem **230**) of a service technician. The message includes:

- the site location (LOC from the CONFIG data);
- the unit number describing the refrigeration equipment (UNIT from the CONFIG data);
- the sensor value that has triggered the fault; and
- an appropriate message identifying the warning or alert.

Every message that is sent to a pager is logged **324** in a file ("PAGERLOG") located on the permanent storage **222**. Each message is logged with a timestamp of when it was sent, a count of the number of times it was sent, and a placeholder for the timestamp of when a technician responded.

Further messages are sent to the service technician's pager if:

- the period specified by the WAIT parameter (from the CONFIG file) has expired;
- there has not been a response from a technician (that is the technician's response timestamp in the PAGERLOG file has not been completed); and
- the number of retries to be attempted (as specified by the RETRY parameter from the CONFIG file) has not been exceeded.

(7) The MRU may be a single discrete composite unit providing the functions of monitoring, recording, and the sending or sounding or display of an alarm, or these functions may be distributed over a number of subunits, one or more of which subunits may be remotely located relative to one another and relative to the equipment being monitored. And all or part of the MRU apparatus may be provided at more than one location, depending upon requirements. If a service technician is constantly monitoring the data compiled and displayed by the MRU, an alarm may be redundant. The specific choice of MRU or MRUs

and the functionality of same are within the discretion of the designer, installer and user of the monitoring system according to the invention. The arrangement of Figure 2 is suitable for many installations.

5 With reference to Figure 2, at any time, and particularly in response to a page received from the MRU, a service technician can connect a conventional personal computer ("PC", not shown) running monitoring software (the "PC Monitor") **240** to the MRU **204**. Note that depending upon the installation, a so-called "dumb terminal" could be substituted for the PC Monitor **240**; in some cases, a passive display monitor, perhaps with the addition of an  
10 alarm, may be all that is required. However, the use of a PC with a PC Monitor permits a high degree of interactivity between the MRU and the technician monitoring the refrigeration equipment, and will in many cases be preferred.

The connection between the MRU **204** and the PC Monitor **240** can be effected in a  
15 number of ways, all of which are conventional. If the service technician comes to the site at which the monitoring event has occurred, the PC Monitor **240** can be connected directly to the serial port **220** on the MRU **204** with an appropriate standard serial cable **242**. Alternatively the technician can connect the monitoring PC from a remote location to a serial port **220** on the MRU **204** by a dial-up modem connection (using modems **234** and  
20 **238** over the telephone network **228**). Lastly, where an internet connection **244** is available at the site of the refrigeration unit, a remote connection can be made from the PC Monitor **240** to an Ethernet™ port **224** on the MRU **204**.

The details of the communication and the protocols used between the PC and the MRU  
25 rely on conventional techniques and can be varied to meet the needs of individual sites.

(8) The PC Monitor **240** provides the following capabilities for service technicians:

(a) Notification of service call

30 The service technician can notify the MRU **204** that the warning or alert has been received and a service call is underway. This is done by the PC Monitor software by sending a request to the MRU software that the technician's response timestamp in the PAGERLOG file be updated to show that the service technician has begun looking at the problem.

35 (b) Maintenance and synchronization of the CONFIG file.

Both the PC Monitor and the MRU software need to use the same set of configuration parameters as are set out for the CONFIG data in (1) above.

The PC Monitor provides appropriate screen edit boxes for a technician to manually enter or revise all of the configuration parameters. These edit boxes are typically organized for convenience on more than one screen. Figure 4 shows the layout of the configuration parameters appearing on an exemplary such screen shown generally as **402**. The values displayed as selections **404** to **410** and in the edit boxes **412** to **430** are all specific to the particular refrigeration unit selected from the "Sensor Group" section **438**. Alternatively, as is described below, the technician can run the PC Monitor in "learn" mode for a suitable period, typically 24 hours, to calculate a selection of the parameters from actual observations of the refrigeration unit's operation.

Figure 5 shows a second screen **502** for setting a selection of the configuration parameters. Typically, this screen is the same as that of Figure 10 with the panel having the tab "Sensor Defaults" **504** being overlayed with a panel having an identifying tab "System Settings" **506**. In the "System Settings" region of the screen there is a selection box **508** to turn pager calling on or off and edit boxes to set values for the modem initialization string **510**, the pager phone number **512** and the number of grace cycles **514**.

Further parameters contained in the CONFIG data are set on other screens (omitted for brevity) similar to those shown for Figures 4 and 5.

The PC Monitor allows the technician to:

- upload the contents of the CONFIG data located on the permanent storage attached to the MRU (not shown);
- edit the values of the CONFIG parameters locally on the PC Monitor, optionally incorporating some appropriate values from "learn" mode, described below. As appropriate, the technician can choose to have these values saved locally on the PC (**434** in Figure 4) or cancelled (**432** in Figure 4);

- download the values for the CONFIG parameters from the PC Monitor to one or more files located on the permanent storage found on the MRU.
- use the values of the CONFIG file parameters most recently uploaded (and possibly revised) with the other functions provided in the PC Monitor software.

(c) Learning mode

In learning mode, the PC Monitor requests a feed of sensor values, during a period of satisfactory normal operation, from the MRU in the same way as is done by the real time monitor (described below). Typically this is started by a button as is shown in Figures 4 and 5 as **436**. The digital sensor values, usually the line voltage  $V$ , the compressor current  $A$ , the defroster current  $D$ , the refrigeration chamber temperature  $T$ , the evaporator pressure  $LP$  and the condenser pressure  $HP$ , are recorded in a database on the PC's hard drive. From these values recorded over a suitable period, typically 24 hours, and at a suitable frequency, typically once per second, a selection of key operating parameters, representative of normal operation, are calculated. Typically, these include:

$V_{\max}$	The maximum line voltage.
$V_{\min}$	The minimum line voltage.
$A_{\max}$	The maximum current drawn by the compressor as it starts up.
$ON_{\text{avg}}$	The average compressor on-cycle duration.
$OFF_{\text{avg}}$	The average compressor off-cycle duration.
$LP_{\min}$	The lowest pressure observed in the evaporator before the compressor shuts off.
$LP_{\max}$	The highest pressure observed in the evaporator before the compressor starts up.
$HP_1$	The maximum pressure in the condenser during compressor operation.
$HP_2$	$1.2 \times HP_1$
$D_{\min}$	The minimum defroster current drawn during defroster operation.
$D_{\max}$	The maximum defroster current drawn during defroster operation.



These values are displayed on a screen (for example, Figure 10) where they may be revised by the technician based on the technician's experience with similar equipment.

5                      Optionally, the values may be saved, in which case the corresponding values for these parameters are updated in the CONFIG data located on the PC.

10                      (d)      Real-time monitoring

The technician can set the PC Monitor to report in real time on the state of a selected refrigeration unit. This function is requested by the click of an on-screen button. The typical operation of this function is shown in Figure 6. In this mode the PC Monitor software:

- 15                      •            requests a repeated transmission (steps **604** to **610**) of digital sensor data as it becomes available at the MRU. The following description provides an overview of how this is implemented in a conventional manner with asynchronous communications.

20                      The transmission of digital sensor data from the MRU to the PC Monitor is configured (step **602**) using the same control bytes as are used by the MRU to control the SCU and which are described above with reference to Figure 2. For example, if six sensor signals are selected for transmission 10 times per second, the PC Monitor will receive 12 bytes (step **604**) from the buffer (not shown) attached to its serial port and after subsequent delays of 0.1 second (step **608**) can expect to find a further 12 bytes waiting in the serial port's buffer on each iteration. This data feed continues until the technician intervenes to stop the feed (step **610**) by clicking on an on-screen button (not shown). The MRU receives notification to stop transmission by the receipt from the PC Monitor of the stop byte (0xF0).

30                      In step **606**, each set of values for the sensor signals are converted to their more normal units (that is pressures in pounds per square inch, currents in amperes and voltages in volts) using the currently active values for the PA, PV, PHP and PLP configuration parameters. The resulting values are placed in a table in shared memory **624**.

- displays the converted sensor signal values on appropriate dials and meters appearing on the PC's display screen.
- starts a separate thread (step **612**) to apply the same diagnostic checks (step **614**, essentially the same as the performance-check step **314** discussed above) to the converted sensor values stored in the shared memory **624** as are described for the SCU in paragraphs (5)(a) - (g) above. The frequency at which this is done is determined by the  $F_2$  configuration parameter. For example, Figure 6 shows the logic flow with a one second delay (step **616**) between diagnostic checks.
- Record in a log (step **620**) on the PC Monitor's display screen the descriptive text and time of occurrence of any warnings or alerts that are detected (step **618**).
- Visually highlight on the PC Monitor display, by way of easily recognizable icons or other suitable means, that a new warning or alert has occurred.
- Continue monitoring sensor values in real time until the technician intervenes to stop the process (step **622**).

Figure 7 shows a sample image **702** from a display screen during the operation of the PC Monitor. This image displays the sensor values converted to regular units for one particular refrigerator unit **704** ("Sensor Group 1 - Main Freezer"). To appear as familiar as possible to service technicians, the values for the compressor current A **708**, line voltage V **710** and refrigerated compartment temperature T **712** are shown as digital instruments; the values for the compressor low pressure LP **714** and compressor high pressure HP **716** are shown as circular dial instruments. The instruments (**708** to **716**) are selected to be large in size to assist in viewing their values at a glance from a distance.

When the PC Monitor detects a fault condition, text **718** describing the type of event, the event's sequence number and its time of occurrence are displayed in a scrollable window **720**. A flashing warning light **706** is turned on at the same time.

(e) Review History database

The History database held in the permanent storage (**222** in Figure 2) contains records of the sensor values uniquely identified by a record sequence number and timestamp. The time range of the historical values stored depends on the amount of permanent storage **222** space available and the frequency with which sensor values are recorded. Typically the sensor values included are the line voltage V, the compressor current A, the defroster current D, the refrigeration chamber temperature T, the evaporator pressure LP and the condenser pressure HP. By way of example, historical data may be kept at one-second intervals for the previous 4 days.

The service technician can request the retrieval of either a selected group of records from the History database or the entire History database. Typically, a subset of the records is selected to provide a one-hour window both before and after a known alert or warning. After the transfer of these records, the historical snapshot can be replayed using a set of button controls that may be selected to resemble those of a cassette tape player, for example. The controls include buttons for:

- skipping to a particular record and in particular rewinding to the beginning of the retrieved historical data;
- replaying the historical values as a multi-line chart. An example of a representative chart is shown in Figure 8;
- pausing or stopping the replay;
- increasing or decreasing the replay speed.

The initial loading of the historical data invokes the diagnostic checks outlined above for each recorded observation. If any warnings or alerts are encountered, an appropriate message and record number are recorded in an on-screen fault list. This is particularly useful when the entire history database is processed as all warnings and alerts occurring during the recent operation of the refrigeration unit can be observed.

Double-clicking on any entry in the on-screen fault list displays more information about that fault. A sample of such a screen is shown in Figure 8. The screen displays an identification of the fault at Incident display **804**, which fault occurred

at a time displayed at Time display **806**. A Statistics panel **803** displays values, measured at the instant of the fault detection, of the record number (Record No. display **808**), the compressor current A (Amperage display **810**), the line voltage V (Voltage display **812**), the compressor high pressure HP (Head Pressure display **814**), the compressor low pressure LP (Low Pressure display **816**) and the refrigerated compartment temperature T (Temperature display **818**).

The chart **820** shows the values of selected sensor values over a period of time displayed as the abscissa **832** of the chart. The sensor values displayed are those selected by the SS parameter in the CONFIG file. In the example of Figure 8, the sensor values selected are the line voltage V (Volts line display **822**), the compressor high pressure HP (High P. line display **824**), the compressor low pressure LP (Low P. line display **826**), the refrigerated compartment temperature T (Temp. line display **828**) and the compressor current A (Amps line display **830**). Values for each sensor are displayed as a separate, distinctly colored line on the chart. (The colours of the chart lines are not shown.) The abscissa is labelled with the record number recorded in the History database corresponding to each point in time displayed. In this example, the records are recorded at one-second intervals. With this information, the technician can observe the behaviour of any of the sensor values during the period leading up to and immediately after the warning or alert.

Figure 9 shows a portion **834** of Figure 8 magnified for greater clarity. The line **902** corresponds to record number 203 and is superimposed on the portion of the chart **834** for ease of reference. The values of the voltage  $V_{203}$  and compressor current  $A_{203}$  indicate that record number 203 is the time at which the compressor motor was activated. Initially, the current  $A_{203}$  drawn by the compressor **106** rises sharply and holds steady at a maximum limit (determined by the compressor manufacturer) as power is required to overcome the inertia of the compressor's components (chart line **830**). Simultaneously, there was a corresponding drop in the line voltage V (chart line **822**). In response to the turning on of the compressor **106**, refrigerant is drawn in from the intake side and pumped out on the condenser side. This is seen in the chart **834** as a reduction of the compressor low pressure LP (chart line **826**) and an increase in the compressor high pressure HP (chart line **824**). Gradually, in response to the work done by the compressor the temperature (chart line **828**) in the refrigerated compartment begins to fall. Under normal

operating conditions, the compressor current falls back to a steady running amperage after approximately one second. However, if the compressor current (chart line **830**) stays locked on at the limiting value for longer than one second, as is the case in Figures 8 and 9, this indicates that there is a problem with either the electrical or mechanical components used in the start-up. The selection of the value for the duration after which a fault is triggered (one second in the example above) is determined by the  $A_1$  parameter set in the CONFIG data.

The detection of faults makes it possible to provide diagnostic information outlining the possible causes of the particular fault detected. Typically, such information can be provided on-screen as a list of likely causes for any selected warning or alert. Such text is kept in a database on the PC and is maintained by the designers of the system.

- (f) Display refrigerated compartment temperature as a time series.

In most locations, periodic inspections by health authorities require the examination of logs of the temperature within the refrigerated compartment. The PC Monitor provides this in the form of a chart by uploading the values of the temperature  $T$  from the History database and displaying (or printing) this as a time series. Typically, values of the temperature are required three times per day for the past 30 days.

- (9) A record is kept of the contractor who installed the refrigeration equipment. Pertinent details recorded include company name, contact person, address, phone number, fax number, email address. There may be several of these sets of data, one for each SCU installed.

- (10) A record is kept of the service history for a site's refrigeration equipment. An example of a service record entry is shown generally as **1002** in Figure 10. For each service visit, details recorded include: a brief description of the problem (Incident display **1004**), the date and time (Time display **1006**), the record number in the history file (Record display **1008**), the compressor current  $A$  (Amperage display **1010**), the line voltage  $V$  (Voltage display **1012**), the condenser pressure  $HP$  (Head Pressure display **1014**), the evaporator pressure  $LP$  (Low Pressure display **1016**), the refrigeration chamber temperature  $T$  (Temperature display **1018**), the name of the service technician (Serviced By display **1020**), the date the

service was completed (Date display **1022**), the cost of the service (Cost display **1024**) and additional comments (Comments display **1026**).

Each record of a service call is appended to a service history (History display **1028**). This data can prove to be of considerable assistance for a service technician as:

(a) situations arise where a subsequent service call is required perhaps to fix a problem situation caused by earlier inadequate service; and

(b) a review of the service history may reveal consistent patterns of component failure which would otherwise go undetected.

### **Alternative embodiments**

Figure 11 shows an alternative embodiment of the invention in which multiple refrigeration units are monitored. By way of example, Figure 11 shows three such refrigeration units **100**. Each refrigeration unit **100** has sensors which are connected to an SCU **206** which are in turn connected to an MRU **204**.

In one embodiment, the SCUs are connected to the MRU by twisted pair wiring using the RS232 communication protocol. At suitable intervals, the MRU software polls each SCU **206** for the values of those sensors selected by the SS parameter from the CONFIG file. Each SCU **206** supplies 2 bytes of data per sensor and the resulting data from one SCU provides a record of data to be included in one of several History databases. There is a separate History database for each unit of refrigeration equipment.

In an alternative embodiment, the SCUs **206** are connected as a daisy chain along one twisted pair wire using the RS485 multidrop protocol. In this arrangement, the MRU **204** receives all the data broadcast from all the SCUs and the software is set to select samples from the SCUs at a suitable frequency.

The operation of the MRU **204** is governed in part by the values of the configuration parameters stored in one or more CONFIG files. Where there are multiple SCUs **206** connected to a single MRU **204**, the software operates on a single SCU **206** at a time as selected by the service technician. The required configuration parameters for the selected SCU **206** are read in from the

appropriate CONFIG file. Further, each request by the PC Monitor functions for historical data from the MRU specifies which SCU History database is to be used.

With reference to Figure 3, sensor data values in standard units are stored **318** as time series in the HISTORY database **320**. These records are subsequently used as the source of the values used in the novel performance checks **314** detailed in paragraphs (5)(a) to (g) above. However, this aspect of the invention is not to be limited by the particular scheme selected to store the sensor data values. Other embodiments employing alternative means of storing the information contained in the sensor data are possible within the scope of this aspect of the invention. For example, the performance checks can be satisfactorily executed with the following stored information (in addition to the values of the parameters in the current period):

Line voltage §(5)(a)	$V_{t-1}$ Record the line voltage in the previous period.
Compressor current §(5)(b)	<p>Record the time at which the compressor current most recently rose to exceed <math>A_{max}</math>. Reset this to zero to indicate that the current has fallen back below <math>A_{max}</math>.</p> <p>If in a particular cycle, the compressor current exceeds the maximum, the stored value is given a timestamp which could look like "20021115100256789" which is YYYYMMDDHHMMSSmmm, the last three digits being milliseconds. In the following periods, if the maximum is still being exceeded no change is made to the stored value. However, when the current falls back below the maximum, the timestamp is set to a predetermined value indicating that the condition has disappeared. The value used could suitably be "0". This remains until the maximum is again exceeded at which time, the timestamp is set to an appropriate 17 digit value.</p> <p>The performance check now functions by comparing the current time with the stored timestamp. If the difference exceeds the <math>A_t</math> value obtained from the CONFIG data, then an alarm is triggered.</p>

Compressor on-cycle or off- cycle §(5)(c) and (d)	Record the times at which the compressor current rises above zero (to start an on-cycle and end an off-cycle) and falls to zero (to end an on-cycle and start an off-cycle). Records having pairs of values of {timestamp, rising/falling indicator} could be stored for as much recent history as is desired by the system designer.
Compressor low pressure §(5)(e)	No stored historical values required as the checks rely only on values in the current period.
Compressor high pressure §(5)(f)	No stored historical values required as the checks rely only on values in the current period.
Defroster current §(5)(g)	No stored historical values required as the checks rely only on values in the current period.

Working example:

For approximately the past six months, testing in secrecy (with appropriate confidentiality restrictions) of an exemplary embodiment of a monitoring system according to the invention, including associated software, has been done. The exemplary monitoring apparatus was installed for use with a typical walk-in cooler, with interior cooling compartment dimensions of approximately 10' x 12' x 7.5' (approximately 3m x 3.65m x 2.3m) . The air-defrost-type cooler specifications are as follows:

Evaporator: 8000 BTU.

Condenser (water-type): 1 Hp.

Control type: Pressure Temperature.

Refrigerant Selection: R-22 (The monitoring system, however, has been designed to operate with any refrigerant type.)

Supply Voltage: 208/230 V, single-phase.

Target refrigeration compartment temperature range: 33 to 40°F (about 0.5 to 4.5°C).

Cooler Contents: food.

The reference above to "Pressure Temperature" control type means that the cooled space has a thermostat in series with the pressure control component located at the condensing unit. Both the thermostat and the pressure control device have the ability to turn the system on or off if exceeding set limits. For example, the high threshold temperature could be set for 35°F above



which the compressor would run, and the pressure control could be set at approximately 60 psi for cut-in and 30 psi for cut-out.

Pressure sensors were located on the high and low pressure sides of the compressor. Amperage (current), voltage and temperature transducers were connected to measure current drawn by the compressor, voltage supplied to the condenser, and temperature of the return air stream of the evaporator (located inside the cooler).

Default values generated from the Learning Mode (having accumulated 24 hours of data) were as follows

High voltage:	210V.
Low voltage:	195V.
Locked-rotor current:	15A.
Normal running load current:	2.0A.
Compressor On-cycle:	2411 seconds.
Compressor Off cycle:	1363 seconds.
Normal High Pressure Max:	183 psi.
Normal Low Pressure Max:	66 psi.
Normal high Pressure Min:	138 psi.
Normal Low Pressure Min:	37 psi.
High pressure too high:	220 psi.
Low Pressure too low:	30 psi.
Low pressure too high:	79 psi.

The monitoring software was chosen to operate on a conventional Windows operating system platform. The software interface application used was a wizard-driven program. A technician or other user of the monitoring system, when the application is loaded and launched, first sees the dialog box of the monitor screen print of Figure 12. The "Wizard Chooser" presents in this example five options for adding, removing and/or configuring a monitored system or retrieving or uploading data. The next following screens show the configuration of the sample system. Each Wizard screen displays in turn the user selection options for the steps that are required in completing the user-selected task, and then the Wizard leads the user through each of those steps. The Back and Next buttons guide this process (See e.g. Figure 13). The particular dialog box of Figure 13 is premised on the selection by the user of the second of the five options displayed in the dialog box of Figure 12. If the user is satisfied with the default settings and simply wants to investigate an apparent present fault condition, the user may exercise one of the last two options displayed among the total of five options displayed in the dialog box of Figure 12.

A technician may wish to use the same interface software to monitor a number of refrigerators, coolers, etc. In this example, the monitor screen print of Figure 14 illustrates a representative five choices. The user first selects the system that he wishes to configure, then clicks the Next button, as directed by the dialog box of Figure 14.

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The default settings for the sample system are shown in the dialog boxes of the screen prints of Figures 15 and 16. The parameter values displayed in the dialog box of Figure 15 were in this working example (and are typically) generated from a 24-hour sample set of data. However, the technician can manually edit any of the displayed values to override the default values by keying in substitute data in any data field displayed in the dialog box. The dialog box of Figure 16 permits selection of default options for the various types of equipment and equipment components displayed.

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Figure 17 is a screen print illustrating a dialog box for displaying selected present or historic parameter data. In the particular screen print illustrated, it is apparent from the voltage reading that a total loss of voltage has been detected. The Alerts box in the lower right of the screen displays three warning/alert messages reflecting possible fault conditions that were detected. These three messages are the following:

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Low-Voltage: The monitoring system has detected a voltage reading below the Low Voltage threshold established by the reference values set by the system or the technician - in this example, 195V as established using the dialog box of Figure 15.

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Power Outage: The system detected no line voltage and thus generated this error message. Note that if this message is displayed, it necessarily follows that the Low-Voltage message would also be displayed.

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Short Compressor Cycle: The monitoring system detected a shorter than normal On Cycle (again apparently because of the loss of power to the compressor).

If the user double-clicks on a message field in the Alerts window of the dialog box of Figure 17, then the screen of Figure 18 appears and presents the user with details of the event, including a graph showing data before and after the event. In this example, the loss of voltage (a drop from normal voltage to zero volts) depicts a representative malfunctioning of the monitored refrigeration equipment. This voltage drop can be simulated for test purposes simply by opening the circuit breaker for the compressor.

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In the exemplary system, any time a message is generated to appear in the Alerts box of Figure 17, concurrently a fault-condition alert or warning message is transmitted to the attending technician's pager. The technician in response to such message can then proceed to examine

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the historic data using the screen interfaces of Figures 17 and 18 for further assistance in diagnosing the apparent fault condition.

In the set of graphs displayed in the historic parameter data display box of the monitor screen print of Figures 18 and 19, the following graphs appear:

First (top) line: Supply Voltage.

Second line: High Pressure HP.

Third line: Low Pressure LP.

Fourth (bottom) line: Current Draw of the Compressor.

Normally the refrigerated space temperature would also appear in the graphs of Figures 18 and 19.

The warning/alert messages of Figure 17 and the associated graph display of Figure 18 alerted the technician to three areas of concern all attributable to the loss of line voltage. Apart from any alert/warning messages, an inspection of the historic data graphs can reveal fault conditions. For example, referring to the historic data graph appearing in the screen print of Figure 19, it can be seen that the High Pressure (HP) and Low Pressure (LP) plots are significantly inconsistent from left to right across the graph, which inconsistency reveals a potential fault. In the graph of Figure 19, approximately three days' data are displayed. The graph reveals high head pressure readings and long daytime compressor cycles. The three sawtooth patterns in the high-pressure (HP) parameter plot and the corresponding three sawtooth patterns in the low-pressure (LP) parameter plot represent a series of sequential on-off cycles of the compressor during the night. But very long almost continuous compressor on-cycles were observed during the intervening daytime periods - the compressor was running almost all of the time. These displayed data prompted the attending technician to visit the site at which the monitored refrigeration equipment was located. The very severe voltage drop at the end of the first sawtooth was caused by the opening of the circuit breaker by the attending technician.

The attending technician discovered on-site that the site had undergone some minor renovations in the course of which some rerouting of the water supplied to the water-cooled condenser had occurred. When the dishwasher and spray wand supplied by the same water supply on premises were operated, the condenser was being 'starved' of cooling water. The remedy for the problem in this case was a plumbing remedy. The attending technician by on-site inspection also discovered low refrigerant levels in the system. This discovery occurred well in advance of what would have been discovered without the warning/alert message. The technician was also able to identify a problem with the thermostatic expansion valve. This was causing the system to run inefficiently because the compressor was not running at full capacity (indicated by relatively low

current draw at the compressor). Many refrigerators include a superheat setting; in this example, a minor adjustment to the superheat setting solved this problem. Repair of the leak was made and the owner was briefed on the water flow problem. It is significant to note that the actual temperatures inside the cooling chamber never exceeded the safe limits even though the system was verging on breakdown.

Note that the ordinates of the graphs of Figures 18 and 19 are different from one another. Preferably the user has the capability in the software set-up to adjust the range and resolution of the ordinate for optimum display of the data on-screen. Note, for example, that the visible variance of the compressor current is small in these graphs; it would be improved by a change in scale of the ordinate for compressor current.